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Creation of ultra-high energy density matter using nanostructured targets on Titan laser

J. Park, R. Tommasini, R. London, J. Rocca, R. Hollinger, C. Bargsten, V. Shlyaptsev, H. Chen, A. Pukhov, M. Capeluto

February 1, 2016

Creation of ultra-high energy density matter using nanostructured targets on Titan laser
Livermore, CA, United States
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Disclaimer

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NIF / JLF User Group Meeting 2016

J. Park, R. Tommasini, J. Rocca, R. London,
R. Hollinger, C. Bargsten, V. Shlyaptsev, H. Chen,
A. Pukhov, M. Capeluto, M. Hill

February 2, 2016

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Lawrence Livermore National Laboratory

The Jupiter Laser Facility serves a wide range of the science communities

- **Great training ground for students**
  - Hands on experience over extended periods of time
  - Exposure to various diagnostics (facility owned and collaborations)
  - Opportunities to interact with experts
  - Student Friendly staff to answer questions and assist
- **Superb experimental platforms**
  - Three target areas that compliment each other: Comet, Janus, and Titan.
  - Flexible laser configuration enables to investigate a wide range of laser plasma physics.

The Jupiter Laser Facility offers the best experimental platforms to
train students,
test new ideas and diagnostics, and
scale up table-top laser experiments to higher laser energy experiments.

Research Team

Lawrence Livermore National Laboratory

Experiment: Riccardo Tommasini, Hui Chen, Jaebum Park
Simulation: Rich London

Colorado State University

Experiment: Professor Jorge Rocca, Reed Hollinger, Clayton Bargsten
Targets: Maria G. Capeluto
Simulation: Vyacheslav Shlyaptsev

University of Dusseldorf, Germany

Simulation: Alexander Pukhov

Atomic Weapon Establishment, U.K.

Experiment: Matt Hill

Outline

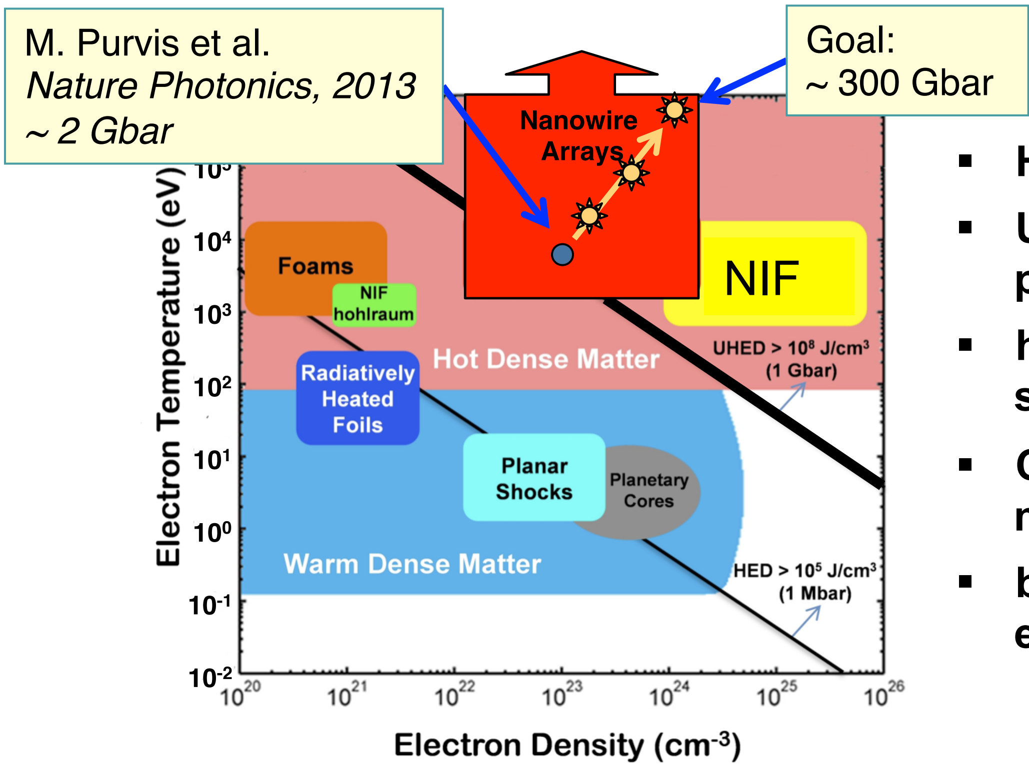
- **Motivation**
  - Achieving extreme plasma conditions: M. Purvis et al. *Nature Photonics, Oct. 2013*

- **Nanostructured targets**
  - Required laser conditions
  - Scaling to Titan laser

- **First experiment on Titan laser**
  - Reduced reflectivity
  - Increased x-ray emission and conversion efficiency
  - Increased electron energy and signal

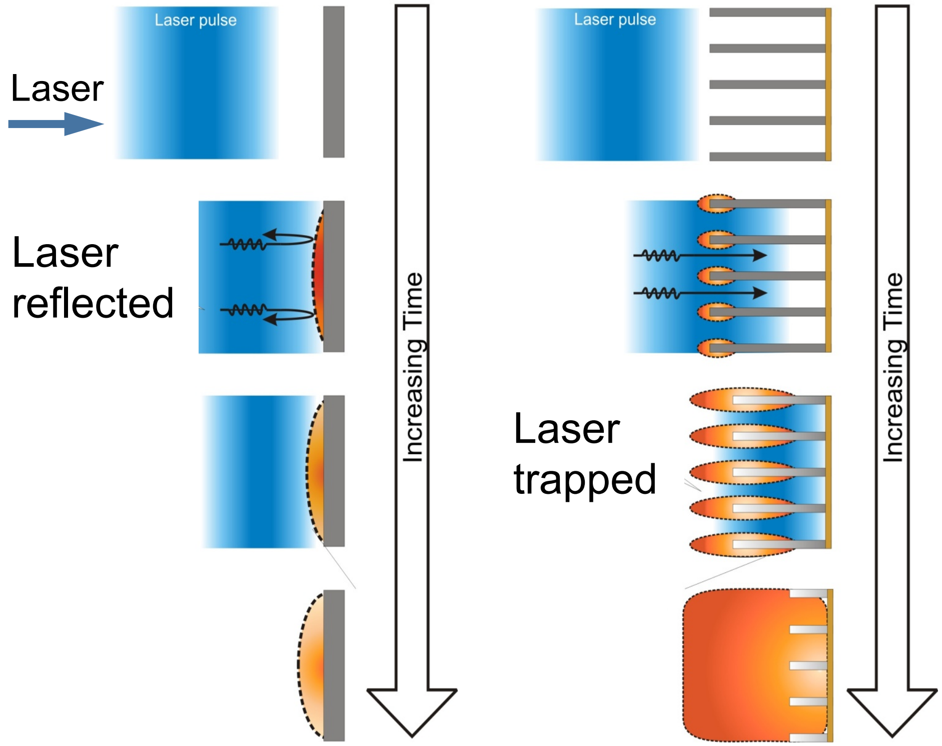
- **Summary / Conclusion**
  - Nanostructured targets for new scientific platforms and x-ray sources

Nanostructured targets can achieve higher energy density than NIF can achieve via Spherical compression of fuel



- Highly ionized
- Ultra high energy density (UHED) plasmas
- high-flux high-energy x-ray radiation source
- Complement to traditional long pulse methods, i.e. NIF
- benchmarking of PIC/HYDRO codes at extreme regimes

Nano wire arrays trap laser light and induce volumetric heating of near solid density matter

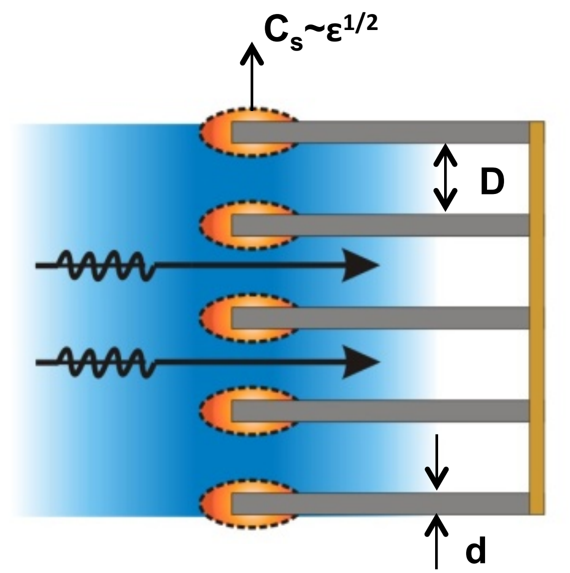


Requirements

- High contrast laser
- Laser pulse length shorter than Plasma expansion time

High density increases ionization rates and radiation efficiency.

Laser pulse length and fluence determine the wire-wire gap (D) and wire diameter (d)

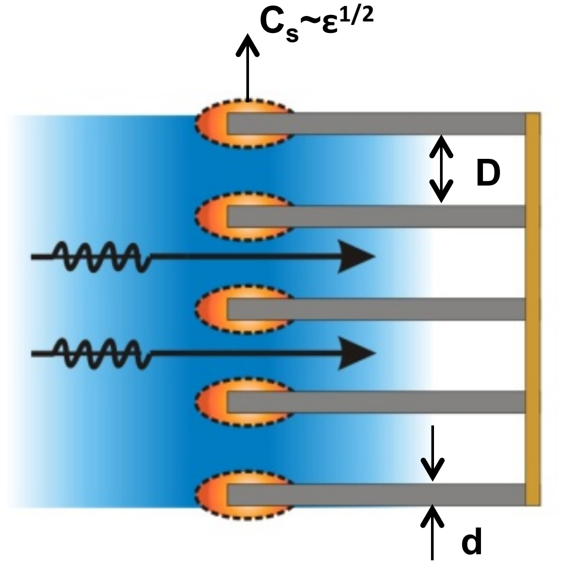


Condition:

$$D/2 \geq C_s\, t_l$$

	Quantity	CSU	multiplier	TITAN	units
Energy	E	0.5	100	50	J
Spot size	s	15	1	15	um
Laser pulse length	t_l	60	8	500	fs
Laser Fluence	F	2.2E+05	100	2.2E+07	J/cm^2
Wire-Wire gap	$D \sim F^{1/3} t_l^{2/3}$	141	19	2700	nm
Wire Diameter	d ~ D	55	19	1050	nm

Simple scaling suggests ~1 µm wires could achieve Energy densities up to ~ 10GJ/cm^3 using Titan laser



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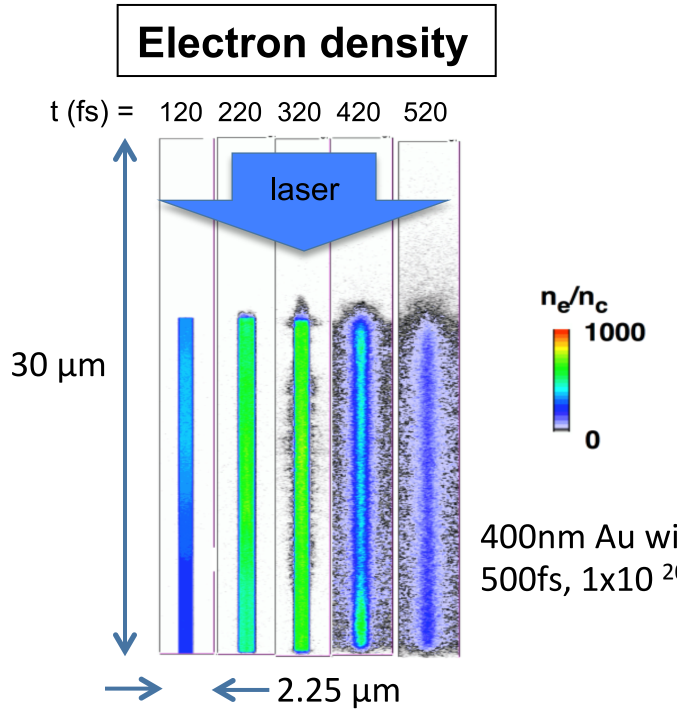
Wire Diameter	d ~ D	55	19	1050	nm
Energy Density	$\varepsilon \sim F/D$ $\sim F/d$	2	5	10	GJ/cm^3

3-D PIC shows that the ponderomotive potential confines the wire longer than the $C_s t_l$ scaling



400nm Au wire
500fs, 1×10^{20} W cm^{-2}

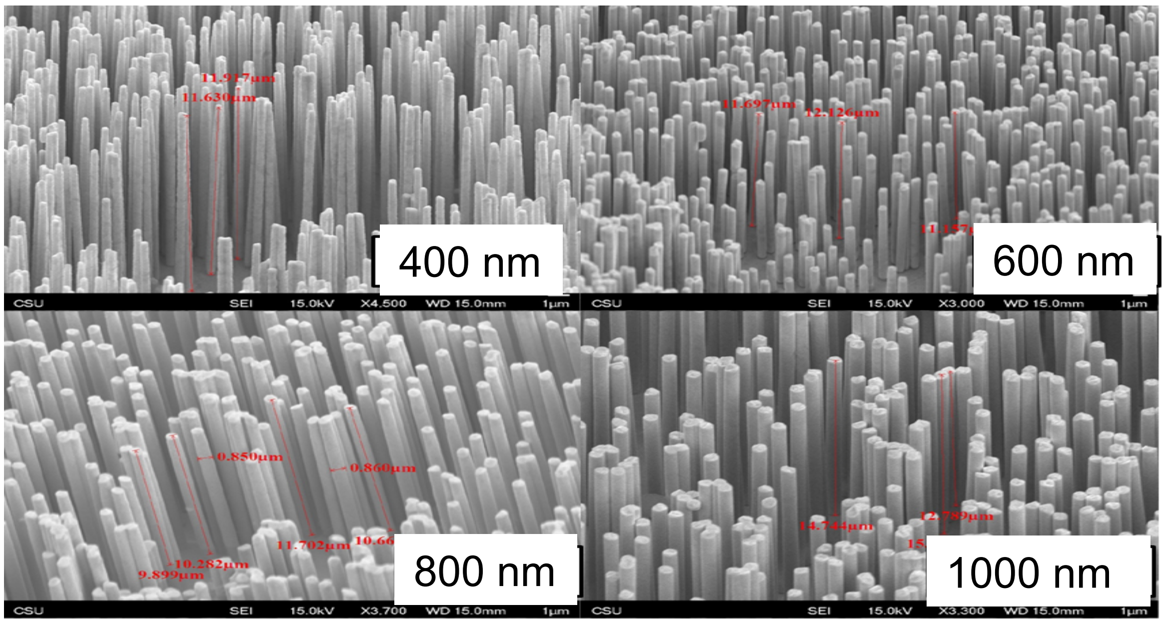
Wires with 400 ~ 800 nm diameters could be used on Titan laser

Even higher energy density, ~ 100 GJ/cm^3, could be reached

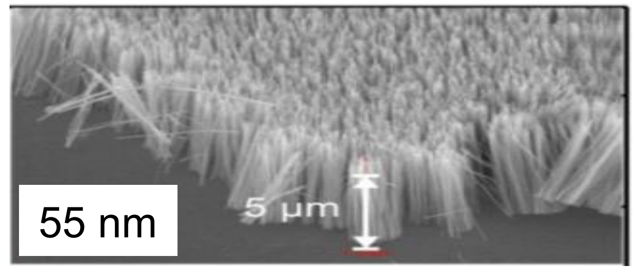
~ 0.1 laser energy conversion efficiency into x-rays is expected

Colorado State Univ. fabricated larger diameter nanostructured targets for the TITAN experiment

Targets for Titan experiment

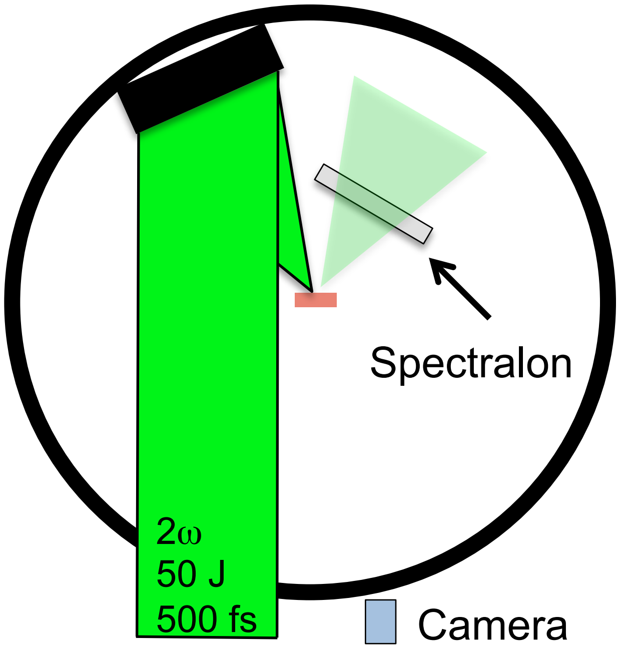


Targets for CSU

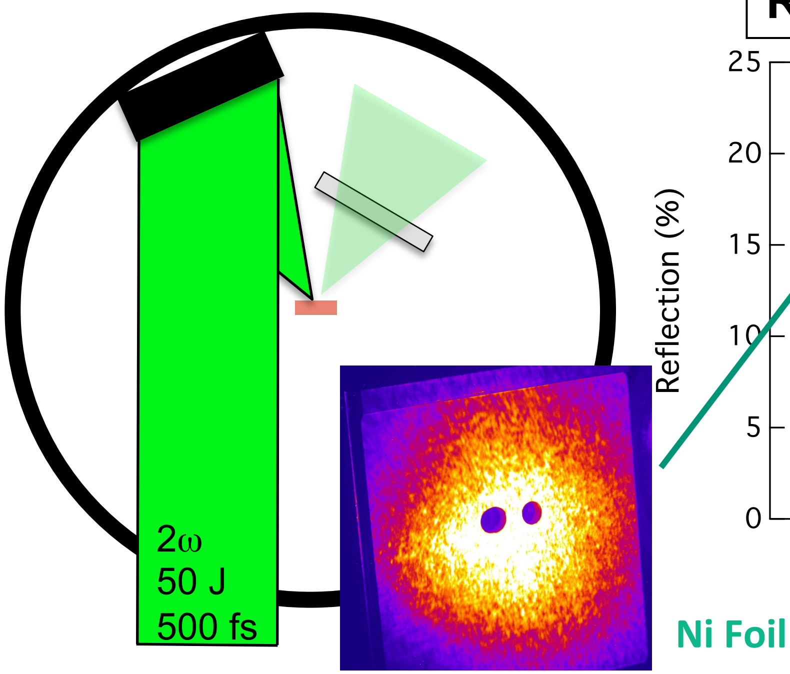


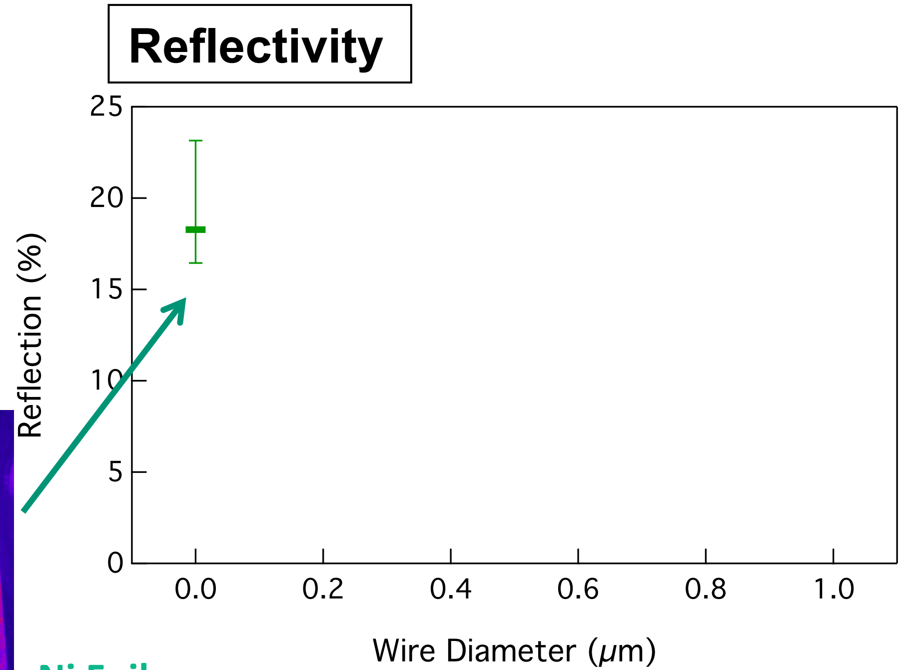
High contrast 2ω Titan laser was used to compare the performance of nanowire targets against flat targets

Setup to measure reflectivity



The 5x decrease in reflectivity indicates much higher laser energy coupling into nanowire targets





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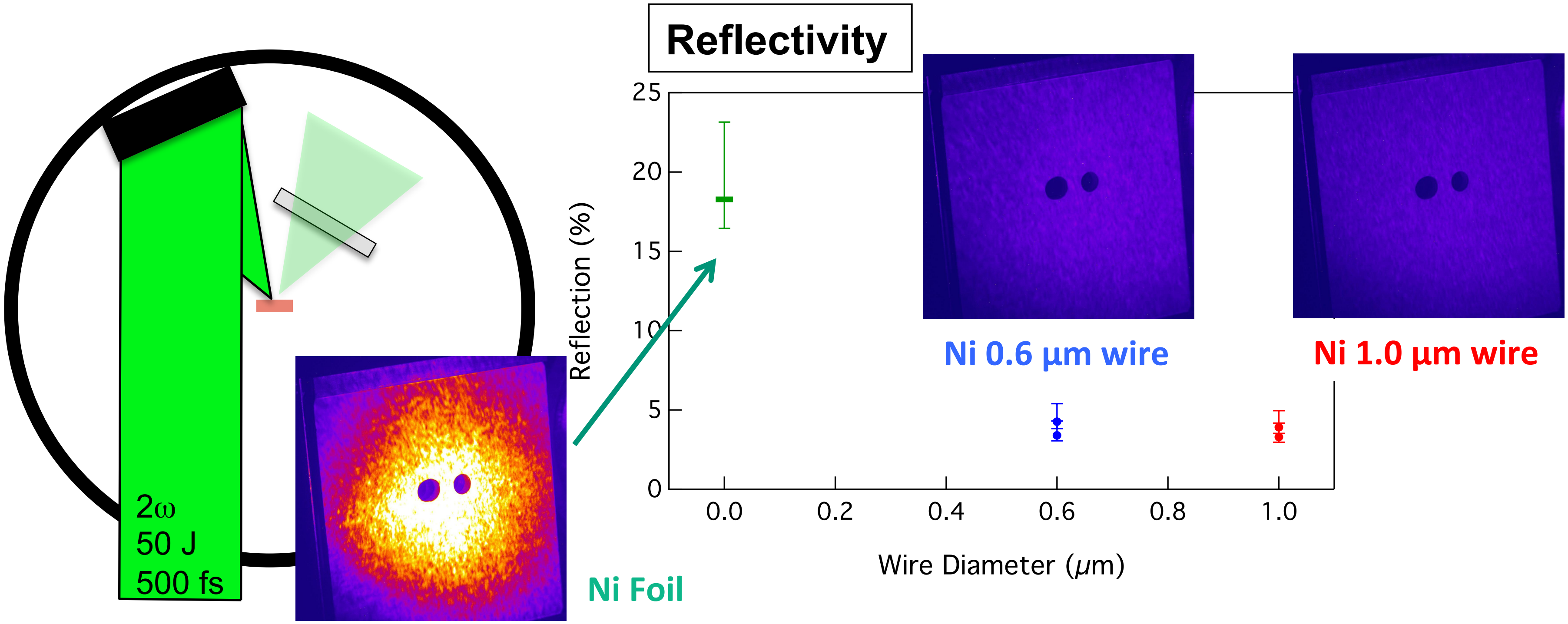
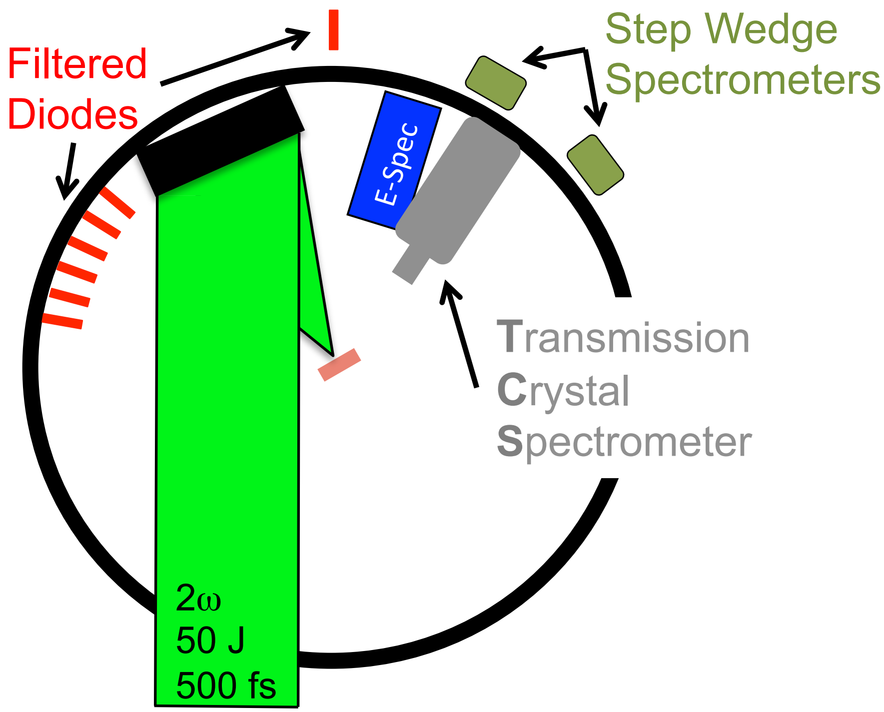


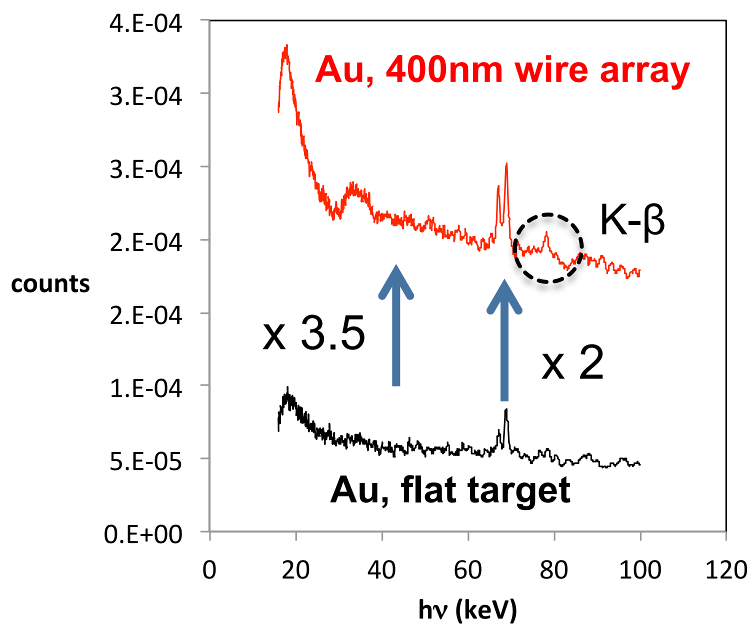
Various diagnostics were fielded to measure x-ray emission and electron spectrum from nanowire and flat targets

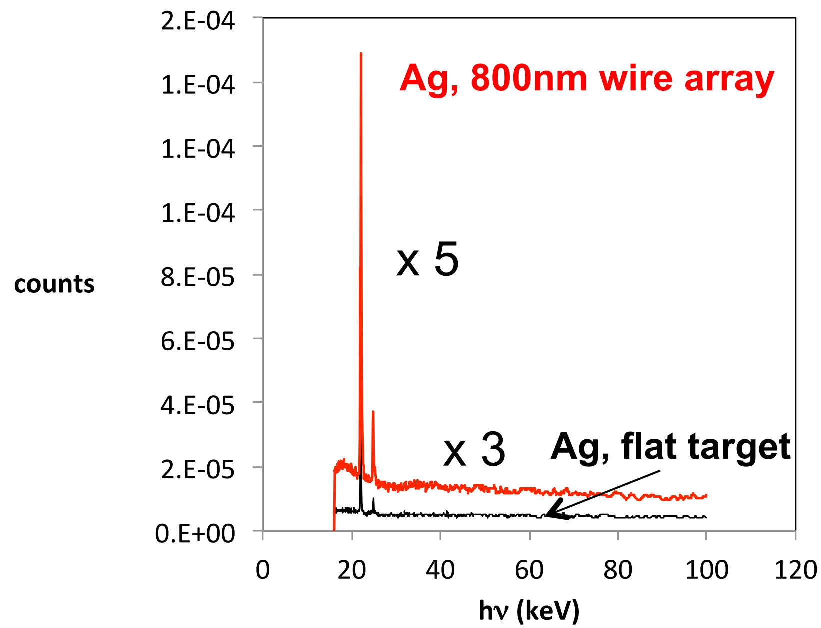


- **TCS:**
  16 - 100keV, x-ray Spectra
- **Step Wedge Spectrometers :**
  40-800 keV, electron temperature, conversion efficiency
- **Filtered Diodes:**
  > 14 keV, Angular x-ray emission, conversion efficiency
- **E-Spec:**
  up to 110 MeV electrons

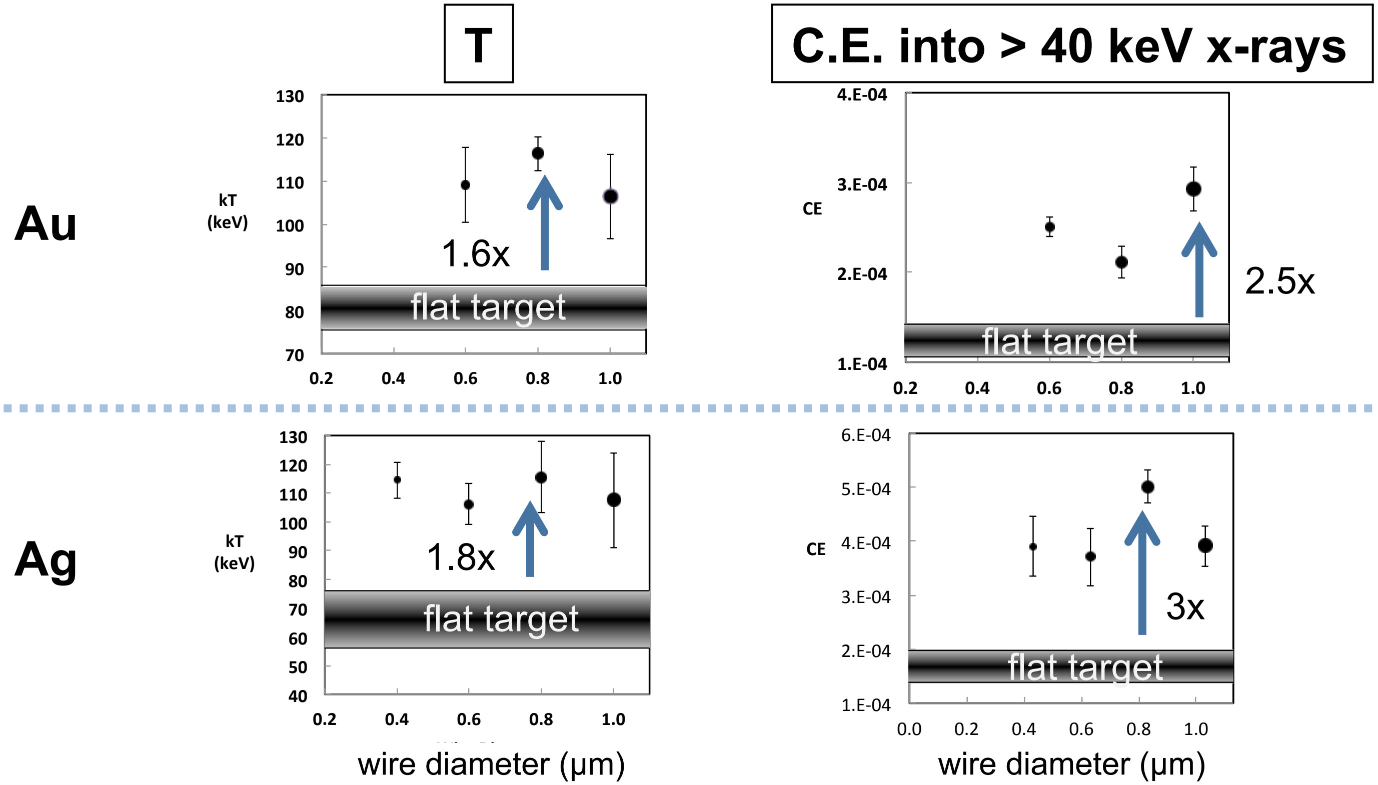
Great increase in continuum and K-α emission were recorded using nanowire targets (Au and Ag)

X-ray spectrum (continuum and K-α)

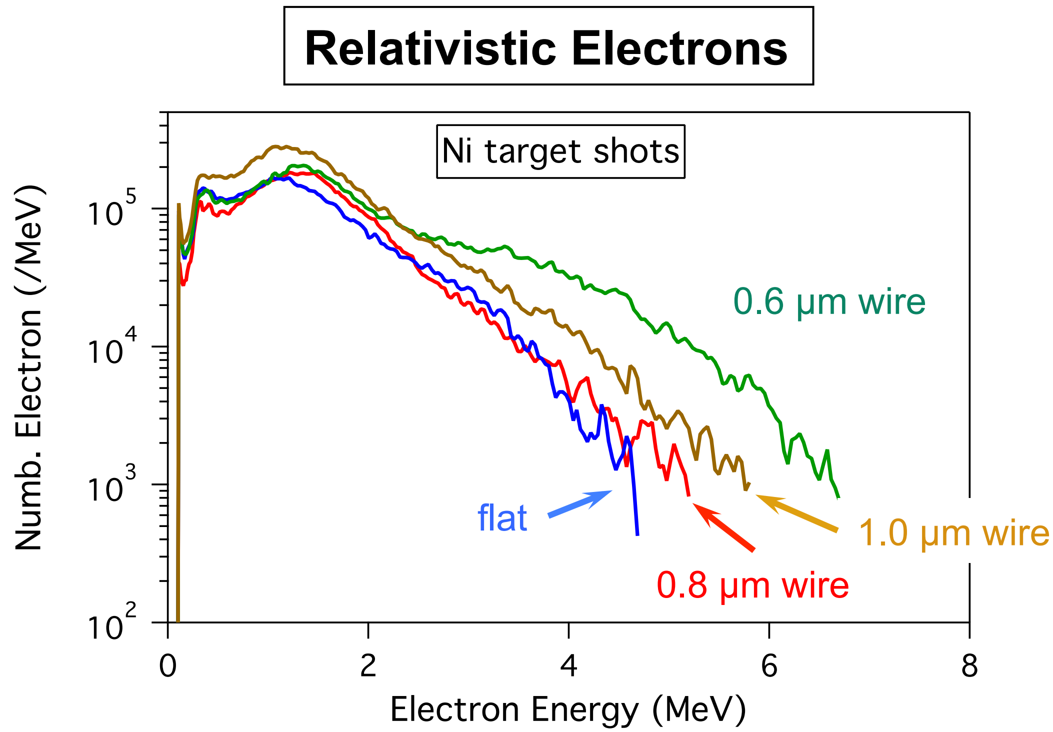




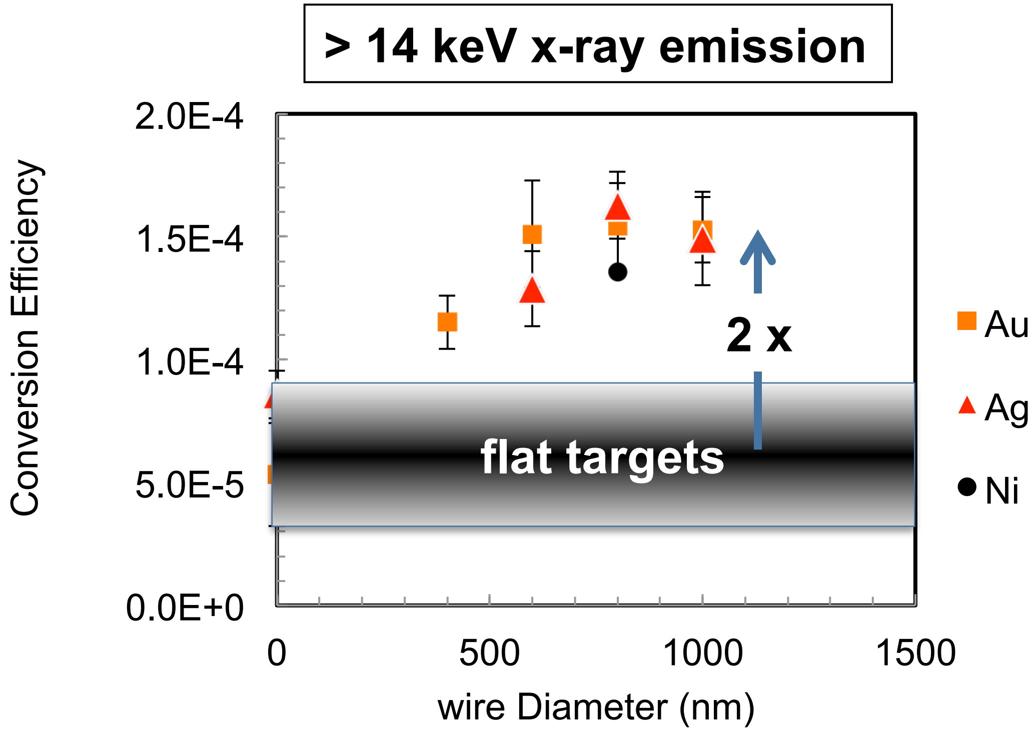
Continuum emission showed large increase in temperature and conversion efficiency into x-ray with nanowire targets



An order of increase in ~ 5 MeV electron emission was recorded with nanowire targets



Lower energy continuum x-ray showed increased conversion efficiency with nanowire targets



The increase in CE from > 14 keV x-ray emission shows the dependence on the wire diameter.

Nanowire targets show great promise to achieve UHED plasmas and high-flux high-energy x-ray sources

- **Reduced the reflectivity by ~ 5x** :
  laser light trapping and significant increase in laser energy coupling
- **Increased signature K_α emission by 3~5x and continuum x-ray by 3x**
- **Enhanced hot electron temperatures by > 1.6x**
- **Enhanced Conversion Efficiency ~ 3x**

Future work

- Optimization of target parameters: upcoming COMET experiment (4 weeks)
- Simulations

Special Thanks to

Bob Cauble (director)
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Ed Gower
Jim Hunter
Jim Moody
Maura Spragge
Rick Cross
Rob Costa
Scott Andrew
Steve Maricle

Hopeful changes and upgrades at the Jupiter Laser Facility

- **Better experimental experiences with the current laser capabilities**
  - Automated laser frequency conversion at Titan
  - More laser diagnostics: 2ω pre-pulse and pulse length measurements
  - Laser normal incidence: apparatus to prevent damaging laser system by the back reflection
  - More resources to maintain the laser systems

- **Upgrades for the future experiments**
  - A better trigger system: time resolved measurements
  - A second short pulse laser on Titan: x-ray and proton imaging

JLF 2.0

Thank you

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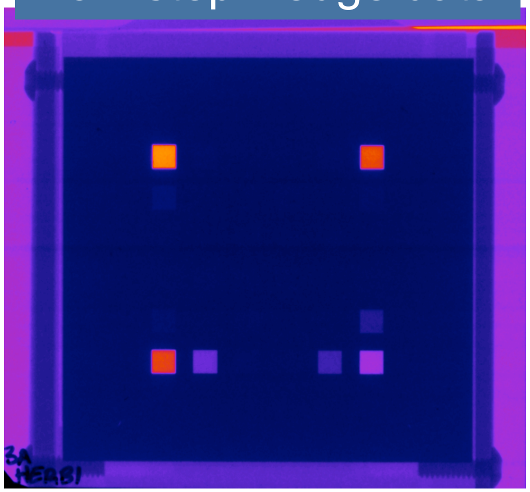
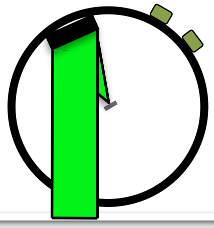
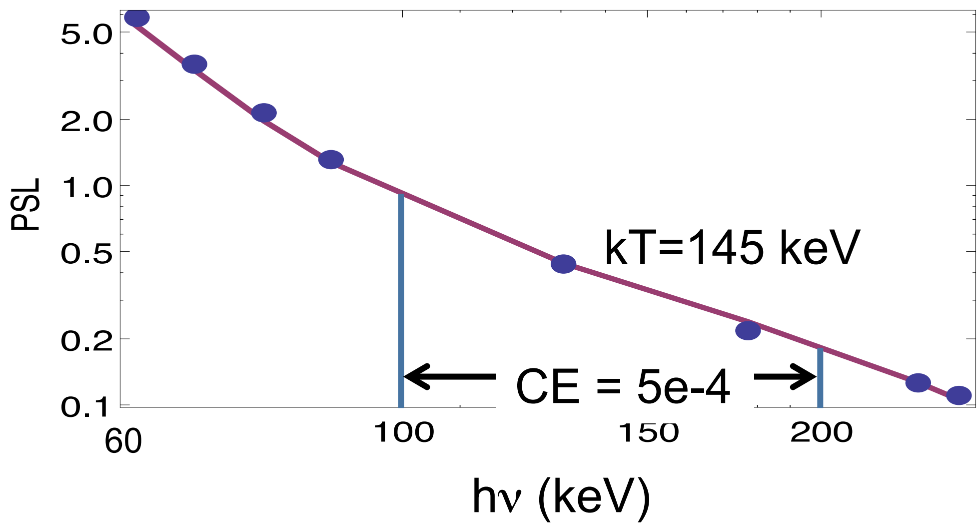
Bremsstrahlung spectra are measured using Ta step wedge with thicknesses ranging from 50µm to 8mm

Raw step wedge data



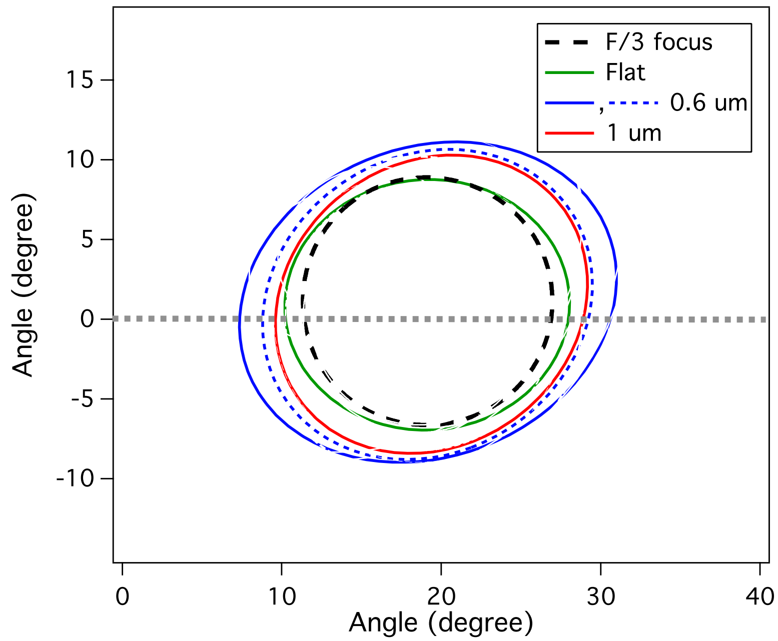


Reconstructed spectrum



The nano-wire targets changes the spatial profiles of reflected laser light

2-D profiles of the reflected light



The reflected light on the laser plane